Radiation Detection with Distributed Sensor Networks

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In any assessment of potential terrorist attacks, the nuclear threat takes center stage. Although weapons-grade nuclear materials are heavily guarded, a plausible scenario involves terrorists detonating a simple radiological dispersion device (RDD) capable of broadcasting nonfissile but highly radioactive particles over a densely populated area. In most cases, a motor vehicle would have to transport the device and its payload—commonly known as a "dirty bomb"—to the target destination. As a final defense against such a weapon, select traffic choke points in the US have large portal monitoring systems to help detect illicit isotopes.

The Distributed Sensor Network project at Los Alamos National Laboratory, in cooperation with the University of New Mexico, is developing a network of radiation detectors that, coupled with other sensors that collect supportive data, is suitable for RDD interdiction in either urban or rural environments. Compared to a portal monitor, a DSN is much less visible, uses less power per detector, is hand carried and thus more rapidly deployable, and simplifies coverage of multiple transport avenues. Also, to function effectively, portal monitoring systems typically require slow or halted traffic, whereas our DSN can be tailored for any moderate traffic speed.

HARDWARE

Expanding on earlier work suggesting that bigger is not necessarily better in radiation detectors,[1,2] our project seeks to provide a flexible, discreet radiation detection solution that enhances not just national security but also global nonproliferation.

Our model DSN consists of arrays of 75-mm sodium iodide (NaI) scintillators directly connected to PDA-sized platforms that provide in situ processing of raw gamma counts. In situ processing eliminates a single point of failure and can potentially weed out faulty measurements. We chose PDAs because they have the processing capability to cope with more complex algorithmic requirements in the future, and a PDA is usually smaller than the radiation detection equipment to which it attaches. Also, PDAs with a general-purpose OS—in this case, Linux—can use familiar and well-tested software tools to manipulate and communicate data.

On each side of a typical two-lane road, 6 to 7 meters wide, we deploy an independently operating array of detectors. The detectors are several meters apart and well away from the roadway, so that the two arrays are approximately 10 meters from each other. In the forward and rear positions and interspersed among the radiation detectors are simpler nodes, such as Crossbow's MICA2 mote, that use accelerometers, magnetometers, and similar sensors to directly detect and track vehicles through the DSN operational space.

METHODOLOGY

To compensate for the smaller detectors' reduced efficiency and source interaction time, the system combines gamma counts across the detection array and coordinates this data with the radioactive source's motion. This *coherent signal addition* method uses an integration window that follows the source as it moves past each detector in the array. During algorithm development,[3] we discovered that when this window length matches detector spacing and expected time lag, increasing the number of detectors also increases the signal-to-noise ratio (SNR) along a $\sqrt{n}$ curve.

In the absence of traffic, the system collects background radiation measurements, compiles these as a mean and standard deviation to produce a baseline threshold, and updates its statistical noise model. When a vehicle approaches the DSN, the forward sensors cue the detection apparatus. These forward units typically detect either seismic vibrations (using an accelerometer) or variations in the local magnetic field (using a magnetometer) and broadcast a time-stamped report when the source exceeds threshold values. This chatter rapidly propagates to the first radiation detector, which informs its neighbors of an oncoming target.

The motes use a separate radio frequency from the PDAs, but one or more PDAs can listen in via an attached mote gateway. Using the mote time stamp, the first radiation detector records gamma counts while the vehicle is within a designated interaction range. For example, the detector can begin counting when the vehicle is 10 meters from its closest approach and cease when it has receded 10 meters. At this moment, the next detector begins

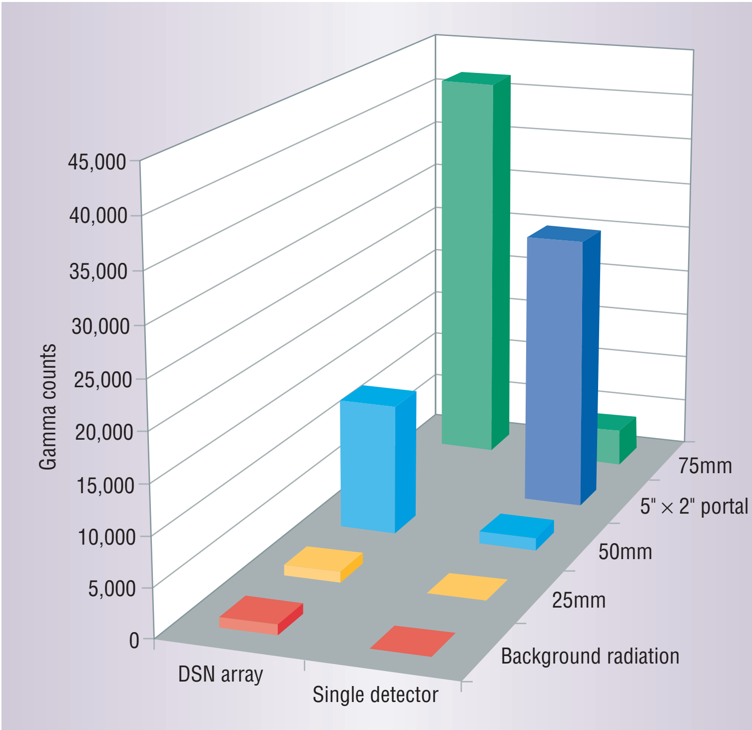

Figure 1. Detector performance. The integration time for one detector is 1 second, yielding a total of 11 seconds for an array. The portal monitor integration time is 11 seconds. Measured background count for the portal monitor is equivalent to that of the entire DSN array.

recording readings, and so on down the array.

In this way, the system passes on the gamma count across all channels minus background noise, along with local background statistics, from one node to the next. The end node adds the values, calculates a threshold from the noise statistics, and determines if the source total significantly exceeds the threshold. If so, the DSN propagates an alert to an uplink for human intervention.

Our analysis assumes that a suspect vehicle will travel at a constant speed ranging from 25 to 45 mph (11-20 m/s). However, future refinements could handle acceleration. Previous research suggests that small accelerations will not greatly impact the SNR.[3]

In practice, we limit the number of detectors to about 11 when using coherent addition. At increasingly larger scales, this algorithm's additive effect on the SNR reaches an asymptote. If our support sensors can provide accurate speed estimates, we can space the radiation detectors more widely and dynamically adjust the interaction window as appropriate for the reported speed. With slower sources, the system would act as if it had regular gaps in the array, yet it would be equally effective.

Alternatively, we could cover various constant speeds, accelerating sources, and, to a hardware-dependent extent, characterize the spectral signature of these sources using more computationally intensive Bayesian methods.

SIMULATION

To thoroughly explore the design space and test our software before field tests, we simulated the DSN along with the technically more efficient portal monitor. We assumed a radiation source composed primarily of cesium-137 due to its industrial availability, typically in powdered form as cesium chloride, and because its extremely high radioactivity would likely promote its use in an RDD. To test our detection scheme's limits, only a small, unshielded mass is transported, equivalent in detectability to a larger measure of the isotope in a lead container of significant thickness.

Our simulations also assumed a speed limit of 45 mph (20 m/s). Given this expected speed, we placed the 11 detectors at intervals of 20 meters within each array and set the detection integration time—how frequently a detector reports its gamma count—at one second.

We expected our simulations to merely show our approach's suitability for certain types of deployments. Instead, we found that the DSN promises improved performance over a single detector to the point of being comparable to some portal monitors that measure vehicles moving at much lower speeds.

We compared the performance of three NaI detector sizes—75, 50, and 25 mm—to evaluate contenders for the radiation detection component. The 75-mm detector is the most common, but the other two are significantly smaller and less expensive. We wanted to establish and quantify the additive effect of our method as well. Using the coherent addition algorithm, we collected a total gamma count across all channels exclusive of background. To bypass shielding effects, we describe the sources in terms of their radioactivity as measured in curies, in this case .01 curie.

As Figure 1 shows, the 75-mm NaI detector array performs distinctly better than one portal monitor over the same total system integration time. The 50-mm detector, also in a coherent additive array of 11 sensors, collects a total count that appears to be sufficient for our purposes because it is still significantly greater than the sampled background. For a small .01-curie source, the 25-mm detector is inadequate even with coherent addition. This demonstrates a limitation of the DSN approach: The system cannot improve resolution if the component detectors collect an insignificant signal.

An individual 75-mm detector is small enough to be convenient, yet an array of 11 outperforms a single portal monitor. Because our system uses many detectors, it can surpass a given performance ceiling and achieve that performance for much faster sources than is typical.

Our simulation studies demonstrate that there is great potential for DSNs to play a significant role in radiation detection. Radiological DSNs can complement the portal monitor approach by enabling rapid deployment and much greater transparency to the public while achieving equal or greater performance.

While we continue to make algorithmic improvements, we are realizing our goal of using commercial off-the-shelf hardware. Our current implementation uses Crossbow MICA2 motes to detect vehicular passage with magnetometers, and Sharp Zaurus PDAs to act as communication bridges between the ISM band motes and the 802.11b PDAs. Other Zaurus PDAs are connected by serial cable to Black Cat Systems Geiger-Mueller tube radiation counters.

In this proof-of-concept implementation, our target radiation source is rather large: approximately 1 curie. This increase by two orders of magnitude is not unreasonable—actual RDDs using this isotope may very well be even larger, without accounting for shielding.

This implementation is extremely inexpensive, and any later detector upgrades will directly yield increased sensitivity. We are currently integrating and testing the component subsystems, and our results are not finalized. However, our experiments to date have validated both the theory and simulation of this DSN.

DSNs show promise not just for radiation detection and rapid response, but also for in situ and real-time detection of a multitude of dangerous phenomena. In the coming years, as sensor hardware improves, we will expand our efforts to reduce other threats such as chemical and biological weapons. ■

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